REPORT NO. NADC-86120-60

(12)

A PULSATING ANTI-GRAVITY SUIT FOR ACCELERATION PROTECTION: SYSTEM DESCRIPTION AND PRELIMINARY EXPERIMENTS

T. W. Moore, B. R. S. Reddy, J. Foley, F. Kepics,
L. Hrebien, and D. Jaron
Biomedical Engineering & Science Institute
DREXEL UNIVERSITY
32nd & Chestnut Sts.
Philadelphia, PA 19104

JULY 1986

INTERIM REPORT
Contract No. N0014-85-K-0566

Approved for Public Release; Distribution is Unlimited

Prepared for
NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Department of the Navy
Bethesda, MD 20814-5044

NOTICES

REPORT NUMBERING SYSTEM - The numbering of technical project reports issued by the Naval Air Development Center is arranged for specific identification purposes. Each number consists of the Center acronym, the calendar year in which the number was assigned, the sequence number of the report within the specific calendar year, and the official 2-digit correspondence code of the Command Office or the Functional Directorate responsible for the report. For example, Report No. NADC-86015-20 indicates the fifteenth Center report for the year 1986, and prepared by the Systems Directorate. The numerical codes are as follows:

CODE	OFFICE OR DIRECTORATE
00	Commander, Naval Air Development Center
01	Technical Director, Naval Air Development Center
02	Comptroller
10	Directorate Command Projects
20	Systems Directorate
30	Sensors & Avionics Technology Directorate
40	Communications and Navigation Technology Directorate
50	Software Computer Directorate
60	Aircraft & Crew Systems Technology Directorate
70	Planning Assessment Resources
80	Engineering Support Group

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS
N/A

2a. SECURITY CLASSIFICATION AUTHORITY
N/A

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE
N/A

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for Public Release

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
N/A

5. MONITORING ORGANIZATION REPORT NUMBER(S)
NADC-86120-60

6a. NAME OF PERFORMING ORGANIZATION
Biomedical Engineering & Science Institute

6b. OFFICE SYMBOL *(If applicable)*
N/A

7a. NAME OF MONITORING ORGANIZATION
Naval Air Development Center

6c. ADDRESS *(City, State, and ZIP Code)*
Drexel University
32nd & Chestnut Sts.
Philadelphia, PA 19104

7b. ADDRESS *(City, State, and ZIP Code)*
Warminster, PA 18974-5000

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
NMRDC

8b. OFFICE SYMBOL *(If applicable)*
Code 404

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
N0014 85-K-0566

8c. ADDRESS *(City, State, and ZIP Code)*
Naval Medical Research & Development Command
NMC-NCR
Bethesda, MD 20814-5044

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
N/A	N/A	N/A	N/A

11. TITLE *(Include Security Classification)*
A Pulsating Anti-Gravity Suit for Acceleration Protection: System Description and Preliminary Experiments

12. PERSONAL AUTHOR(S)
T. W. Moore; B. R. S. Reddy; J. Foley; F. Kepics; L. Hrebien; and D. Jaron

13a. TYPE OF REPORT
Interim

13b. TIME COVERED
FROM N/A TO N/A

14. DATE OF REPORT *(Year, Month, Day)*
July 1986

15. PAGE COUNT
3

16. SUPPLEMENTARY NOTATION
IEEE/EMB Conference, November 1986

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
G-tolerance; Anti-G Suit

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This ~~communication~~ describes a system designed to study the feasibility of augmenting tolerance to acceleration stress using external pressure pulsations synchronized to the electrocardiogram.

The system, known as synchronized pulsating anti-gravity suit, consists of a modified G Suit, a controller and a pneumatic subsystem. The modified suit has individual bladders for calf, thigh, and abdomen with separate inlet/outlet ports. A microcomputer controls the synchronization, phasing and sequencing of pressure pulses in the bladders. Desired high and low pressures are obtained using feedback of pressure signals to a set of comparators. Solenoid valves and related circuitry regulate the flow of air in and out of the bladders. Results based on the centrifuge experiments suggest the feasibility of obtaining improved tolerance with a synchronized pulsating suit.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
L. Hrebien

22b. TELEPHONE *(Include Area Code)*
(215) 441-1490

22c. OFFICE SYMBOL
60B1

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

*U.S. Government Printing Office: 1985-607-047

UNCLASSIFIED

TABLE OF CONTENTS

LIST OF FIGURES

A PULSATING ANTI-GRAVITY SUIT FOR ACCELERATION PROTECTION : SYSTEM DESCRIPTION AND PRELIMINARY EXPERIMENTS

T.W. Moore, B.R.S. Reddy, J. Foley*, F. Kepics, L. Hrebien** and D. Jaron

Biomed. Eng. and Sci. Inst., Drexel Univ., Philadelphia, PA 19104
*Dept. of Aerospace Med., McDonnel Douglass Corpn., St. Louis, MO 63166
**Naval Air Dev. Center, Warminster, PA 18974

ABSTRACT

This communication describes a system designed to study the feasibility of augmenting tolerance to acceleration stress using external pressure pulsations synchronized to the electrocardiogram.

The system, known as synchronized pulsating anti-gravity suit, consists of a modified G suit, a controller and a pneumatic subsystem. The modified suit has individual bladders for calf, thigh, and abdomen with separate inlet/outlet ports. A microcomputer controls the synchronization, phasing and sequencing of pressure pulses in the bladders. Desired high and low pressures are obtained using feedback of pressure signals to a set of comparators. Solenoid valves and related circuitry regulate the flow of air in and out of the bladders. Results based on the centrifuge experiments suggest the feasibility of obtaining improved tolerance with a synchronized pulsating suit.

INTRODUCTION

Use of a standard anti-G suit, muscular straining maneuvers and positive pressure breathing are the most commonly used methods of increasing tolerance to acceleration stress. The standard anti-G suit consists of interconnected bladders for calves, thighs and abdomen. This suit is inflated to a pressure equal to $1.5(G_z-1)$ psi, where G_z is the acceleration in the head-to-foot direction. The pressure applied to the suit prevents pooling of blood in the lower extremities, increases blood pressure in the central circulation and provides G protection of approximately 1G [2]. Certain muscular straining maneuvers and positive pressure breathing, when combined with anti-G suit, increase the tolerance by nearly 2 G[9]. However, the protection provided by these methods is still insufficient, considering the capabilities of today's high performance aircraft.

External counterpulsation, a form of SEP, has been used as a cardiac assist modality in clinical setting [6]. When properly phased, this form of SEP can produce increased cardiac output, diastolic arterial pressure, coronary flow and venous return, and decreased systolic pressure and cardiac oxygen consumption. This technique has been used as a noninvasive treatment for cardiogenic shock and as early treatment of myocardial infarction [1]. The cardiovascular benefits of SEP suggest that this method may be useful for augmenting G tolerance by augmenting cerebral blood flow and enhancing venous return.

The concept of using SEP as a means of increasing G_z protection has previously been investigated [8] but the results were inconclusive, due to equipment limitations. Our earlier theoretical study, using a nonlinear computer model of the cardiovascular system, indicated that SEP might provide increased G protection[7]. More recently, the idea has received further support from other laboratories [10].

The system described in this communication was designed to determine the proper operational characteristics for increased G tolerance. This system will be referred to as pulsating anti-G suit (PAGS). This system has options for choosing different schemes of inflation/deflation sequences, and levels of pressurization. The system requirements included : 1) synchronization of the pressure pulsations to a physiologic signal, say ECG, 2) control of the phasing of the pulsations in the cardiac cycle (systolic or diastolic), 3) individual control of timing and levels of pressurization of bladders and 4) control of the high and low pressure limits (P_H and P_L) during pulsation as a function of G level, so that

$$P_H = P_m + 0.5 \times P_p \quad (1) \text{ and}$$

$$P_L = P_m - 0.5 \times P_p \quad (2),$$

where P_m is the mean pressure which is a function of G_z and P_p is the peak-to-peak excursion around the mean value.

The PAGS system, developed to meet the above requirements was tested on human subjects in a Dynamic Flight Simulator at the Naval Air Development Center (NADC), Warminster, PA.

SYSTEM DESCRIPTION

The major subsystems of PAGS are a modified G suit, a pneumatic subsystem and a controller. The modified suit was constituted of five separate nonconnected bladders: one for each calf, one for each thigh and one for the abdomen. It was obtained by modifying the standard Navy anti-G suit to provide individual inlet/outlet ports to each bladder.

An air supply charged an accumulator to 15 psi through a regulator. Each bladder was inflated by opening the solenoid valve between the accumulator and the bladders. The valve closed automatically when the desired pressure P_H was reached. Each bladder was deflated by venting it to atmosphere using another solenoid valve, which was closed automatically when the desired low pressure level P_L was reached.

Control of the timing, the duration, and the sequence of actuation of the solenoid valves was achieved by using an 8-bit, 6502-based microcomputer. Figure 1 shows the functional blocks of the controller hardware. Inputs to the controller were the ECG of the subject, the G level signal, and the pressure transducer outputs.

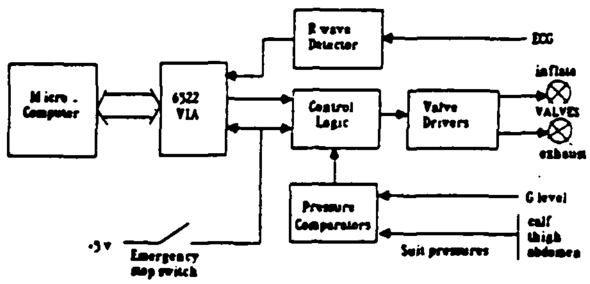

Figure 1. Functional block diagram of the controller

When an R wave was detected, the computer initiated a series of operations which included computation of event timings and generation of INFLATE and DEFLATE signals for all the bladders. On receiving the INFLATE signal from the computer, the valve control logic energized the valve drivers to initiate inflation of the suit bladders. Inflation was terminated when the pressure comparators indicated that the desired high pressure (P_H) had been reached. Similarly, deflation was initiated by the computer-generated DEFLATE signal and terminated by pressure comparators.

An interactive module and a control module constituted the software. The interactive module allowed the user to specify a wide range of parameters for suit pressurization, such as the phasing of inflation (systolic/diastolic), duty cycle, the order of inflation of bladders (simultaneous/sequential), and the delay between inflations of two adjacent bladders for sequential mode. This module was coded in BASIC.

The real time computing tasks were perfomed by the control module which was coded in 6502 assembly language. These tasks included providing a clock base for measuring time intervals and scheduling various events, monitoring the incoming R wave and generating INFLATE and DEFLATE signals. In the sequenced mode of operation, appropriate delays between inflation of the bladders were also generated.

Independent control of pressures in the bladders was achieved by using three pairs of comparators (one each for calf, thigh, and abdominal bladders) and associated control logic. Outputs of the pressure transducers were compared with P_H and P_L in each pair of comparators. An output signal was generated by one of the comparators when the pressure in the bladder increased above P_H. The other comparator generated a similar signal when the pressure fell below P_L. With inputs from the computer and the pressure comparators, the valve control logic circuit provided the biphasic voltages to energize the appropriate valve drivers.

EXPERIMENTS

The system was tested under 1G conditions in the laboratory and under various G_z acceleration levels in the Dynamic Flight Simulator (DFS) at NADC.

The laboratory tests, involving six student volunteers, were conducted in order to confirm the correct functioning of the system and to examine some of its physiological effects. Parameters varied during these tests included timing and duration of bladder inflation, delay between bladder inflations in the sequenced mode, and high and low pressure limits.

The PAGS system was then installed in the DFS and tested on seven relaxed US Navy volunteers. Based on results from the static tests, several operating modes were used including simultaneous and sequential bladder inflation and systolic and diastolic pressure application. The effects under both rapid and gradual Gz onset runs were recorded. The results of these tests have been reported elsewhere [F1,F2].

RESULTS

The PAGS system was able to deliver pressure pulses, correctly synchronized and phased to the cardiac cycle, both in the laboratory tests and in the DFS. Although cockpit R wave detection is a much more difficult task, missed R waves in these experiments occurred in only two out of 300 runs. Doppler and plethysmographic records clearly indicated the augmentation of pressure and flow pulses produced by the pulsating suit. Of the operating modes tested, pulsations timed to correspond with cardiac systole resulted in the greatest increase in Gz protection.

Difficulties encountered with the system in these experiments often had the general effect of causing the mean suit pressure during pulsations to fall below that of the standard suit. It was found that the high and low pressure set point voltages resulted in pressures below those desired if the voltages were set to vary linearly with Gz. The sequential mode was achieved by starting calf inflation at a fixed time after the R wave, then inflating thigh and abdominal bladders after fixed additional delays. This too severely reduced the duration of abdominal bladder inflation at high heart rates. Additional problems were encountered due to delays contributed by the solenoid valves used. These difficulties can be overcome by minor changes in the hardware and software of the system.

Despite the fact that mean suit pressure in the experiments was often lower than that used with the standard suit for given Gz, the measured protection resulting from PAGS compared well with protection offered by the standard suit. Since G_z protection is directly related to suit pressure [5], the results indicate that the pulsating suit might offer a higher protection than the standard anti-G suit when equal mean pressures are maintained.

ACKNOWLEDGEMENT

This work was supported in part by the Naval Medical Research and Development Command contract No. N0014-K-0566.

REFERENCES

1. Amsterdam EA, Willerson JV, Loeb HS, Criley M, Bans JS, Mason DT. Clinical assessment of external pressure circulatory assist in accute myocardial infarction, Amer. J. Cardiol. 1976; 37:116-120.

2. Cohen MM. Combining techniques to enhance protection against high sustained accelerative forces. Aviat. Space Environ. Med. 1983; 54:338-342.

3. Foley JM. External pressure pulsations for acceleration protection: System development and centrifuge experiments. M.S. Thesis, Drexel University, 1985.

4. Foley J, Moore T, Reddy BRS, Kepics F, Hrebien L, D.Jaron. Preliminary experimental assesesment of external pulsations for acceleration protection, in Proc. 33rd Internatl. Cong. Aviat. Space Med. Mexico, Oct. 1985:134-137.

5. Hrebien L, Hendler E. Factors affecting human tolerance to sustained acceleration, Aviat. Space Environ. Med. 1985; 56:19-26.

6. Lilja GP, Long RS, Ruiz E. Augmentation of systolic blood pressure during external cardiac compression by use of the MAST suit, Amer. Emerg. Med. 1981; 10:182-185.

7. Moore T, Jaron D, Chu CL, Dinar U, Hrebien L, White ML, Hendler E, Dubin S. Synchronised external pulsations for improved tolerance to acceleration stress: Model studies and preliminary experiments. IEEE Trans. Biomed. Eng. 1985; 32:158-165.

8. Phillips CA, Rogers DB. Prototype development of the cardiac synchronized augmented pulsation pressure concept, in Proc. Natnl. Aerospace Electron. Conf. 1976:192-199.

9. Shubrooks Jr, SJ. Positive pressure breathing as a protective technique during $+G_z$ acceleration, J. Appl. Physiol. 1973; 35:294-298.

10. Van Patten RE. Current research on advanced concept anti-G suits. in Proc. 23 Ann. Symp. SAFE Assoc. 1985 : 162-164.

DISTRIBUTION LIST
REPORT NO. NADC-86120-60

	No. of Copies
Director, Defense Technical Information Center	12
Commander, Naval Air Systems Command	10
(4 for NAVAIRDEVCEN Liaison Office)	
(3 for AIR-320R)	
(2 for AIR-931H)	
(1 for AIR-531B)	
Office of Naval Technology	2
(1 for ONT-223)	
Commanding Officer, Naval Medical Research & Development Command	2
(1 for NMRDC-44)	
Chief, Bureau of Medical & Surgery	2
(1 for NM&S 3C1)	
Chief of Naval Operations	3
(1 for NOP-05H)	
(1 for NOP-09E)	
Chief of Naval Research	5
(1 for ONR-440)	
(1 for ONR-441)	
(1 for ONR-441NP)	
(1 for ONR-442)	
Commander, Naval Safety Center	1
Commanding Officer, Naval Aerospace Medical Research Laboratory	1
Superintendent, Naval Postgraduate School	1
Commanding Officer, Naval Health Research Center	1
Commanding Officer, Naval Personnel Research & Development Center	1
Commander, Naval Air Test Center	1
Commanding Officer, Naval Biodynamics Laboratory	1
Commanding Officer, Naval Submarine Medical Research Laboratory	1
Commanding Officer, Naval Training Equipment Center	1
Air Force Office of Scientific Research (AFSC)/NL	1
Air Force Aerospace Medical Research Laboratory	2
U.S. Air Force School of Aerospace Medicine	1
U.S. Army Aeromedical Research Laboratory	1
FAA Civil Aeromedical Institute	1
NASA Ames Research Center	2
NASA Johnson Space Center	1
Dr. Banu Onaral, Drexel University	2
Dr. Dov Jaron, Director Biomedical Engineering & Science Institute, Drexel University	1
Dr. Steven Dubin, University Veterinarian, Drexel University	1